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(54) Sensor connection system.

(57) A system for connecting sensors to a control/monitoring system uses concentrators to time-division multiplex groups of sensors onto a bus. The sensors are connected to the concentrator by cord sets. A controller recovers the individual sensor data and supplies the same to the control/monitoring system. The sensors provide "on" and "off" im-

pedances that differ from the "short" and "open" impedance of a cord set. Depending on the voltage the concentrator measures, the concentrator determines if a sensor is on or off, or a cord set is damaged or unconnected. The status of the cord sets is also provided to the controller.

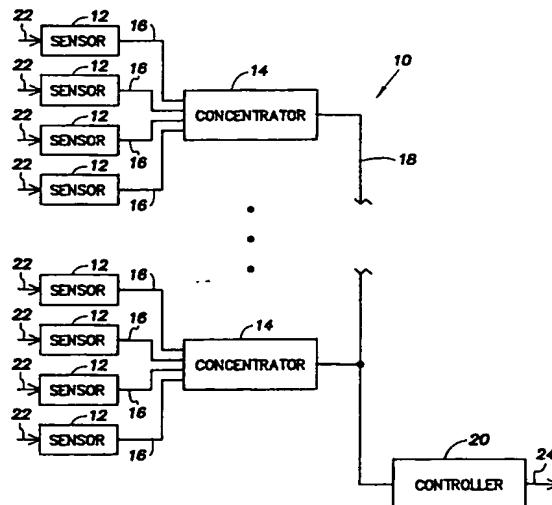


Fig. 1

EP 0 556 991 A1

BACKGROUND OF THE INVENTION

The present invention relates to apparatus for connecting sensors to a control or monitoring system, in particular, apparatus having fault-detecting capabilities.

As computer process control and monitoring plays a larger role in the industrial environment, the capability to connect large quantities of sensors efficiently and reliably to a central location has become increasingly important.

In the past, the process control or monitor for a machine or process has fewer input devices and sensors. In this situation, it was acceptable to wire individually each sensor to the control.

As control and monitoring has become more complicated due to automation needs, sensor inputs have multiplied and the number of wires required has grown very large.

Rather than run individual electrical circuits between each sensor and the control, methods have been used that distribute groups of I/O modules into remote electrical boxes such that each I/O group places sensor outputs onto shared electrical circuits or buses that multiplex the signals back to the control.

It is relatively easy and economical to protect the bus from physical damage because it contains a relatively small number of conductors or other data transmission medium, and it need only directly communicate with each I/O group which are typically located farther from physical hazards.

On the other hand, each sensor must still be located near the condition to be sensed. Unfortunately, it is often too expensive and/or too difficult to protect fully the connection between the sensor and I/O group from physical hazards.

In practice, the connection between the sensors and the remote I/O group electrical box is often the portion of the control/monitoring system most likely to fail. Typically, this connection is in the form of flexible cables with a quick connectors on one end, the other end being hard-wired. While tough and sturdy, these cables are often damaged in the harsh industrial environment.

As process control/monitoring becomes more complicated, it becomes increasingly critical to determine whether a condition received from a remote device is the actual state of the sensor or due to a fault in the sensor or its cable. Not only is it desirable to determine if a cable fault exists, it is also important to be able to identify quickly which cable is faulty.

To minimize costs and complexity, several sensors can be connected to a conveniently located concentrator, which does the necessary transformation to place the sensors' information onto the bus.

SUMMARY OF THE INVENTION

The sensor connection system of the invention provides for the efficient and effective connection of sensors to a central location and the detection of faults occurring in the sensors and the sensor cables.

5 The sensor connection system includes a plurality of sensor units. Each unit provides a first impedance in response to a first sensed condition or a second impedance in response to a second sensed condition. Neither of the impedances provided by the sensor units is indicative of a short circuit or an open circuit.

10 Each sensor unit is connected to a concentrator by a sensor cable having quick connectors on each end. The concentrator provides a first logical signal in response to the first impedance, a second logical signal in response to the second impedance and a third logical signal in response to an error impedance. The error impedance is indicative of a short circuit or an open circuit in a respective sensor cable.

15 20 25 Each bus is connected to the concentrator for transmitting the signals and a controller connected to the bus. The controller causes the concentrator to provide the signals for each sensor unit to the controller. The controller provides a status for each sensor unit to the process monitoring or control system.

20 25 30 35 In the preferred embodiment, the controller provides a clock signal on the bus and the signals are transmitted a first time on the bus by time-division multiplexing in response to the clock signal.

35 40 45 After the first transmission of the signals, the signals are transmitted a second time on the bus in inverted logical form in further response to the clock signal. The first and second transmissions are compared by the controller to detect transmission errors.

The bus provides power from the controller to the concentrators and sensor units. This simplifies the wiring of the system, as no local power is needed.

50 55 The concentrators can be advantageously encapsulated for protection from environmental hazards.

Status lights are provided on the controller and/or the concentrators. This allows rapid identification of system faults. A quick visual inspection shows operators and maintenance personnel where the problem is located. This allows maintenance crews to minimize down-time.

The controller provides sensor status to the monitoring or control system on a plurality of parallel status lines corresponding to each sensor unit. This allows easy interfacing to existing control and

monitoring systems. The status lines simply take the place of hard-wired sensors. No user programming is required.

It is also possible to provide the same signal information to the monitoring or control system by serial data transmission.

An adapter apparatus allows for the connection of contact closure type switch sensors to the connection system of the invention. The adapter apparatus includes a first impedance in series with the switch sensor and a second impedance in parallel with the sensor and first impedance. The apparatus provides the second impedance in response to the switch sensor being open or a third impedance in response to the switch sensor being closed. None of these impedances are a short circuit or an open circuit.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a sensor connection system according to the invention.

FIG. 2 is a block diagram of a connection system according to the invention showing the signals on the bus.

FIG. 3 is a combination schematic and block diagram of sensors and a concentrator according to the invention.

FIG. 4 is a block diagram of a controller according to the invention.

FIG. 5 is a graph showing an exemplary logical data signal for one concentrator.

FIG. 6 is a graph showing an inverted logical data signal for the concentrator of FIG. 5.

FIG. 7 is a top plan view of a concentrator according to the invention.

FIG. 8 is a right side elevation view of the concentrator of FIG. 7.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, a sensor connection system 10 is formed from groups of sensors 12 connected to concentrators 14 by sensor cables or cord sets 16. The concentrators 14 are connected to a bus 18 leading to a controller 20.

Conditions-to-be-sensed 22 act on each sensor 12 which then provides either an "on" or "off" indication. These individual indications are time-division multiplexed by the concentrators 14 onto the bus 18 under the control of the controller 20. As will be more fully set forth below, the concentrators 14 also time-division multiplex the "fault" or "no fault" condition of each of the cord sets 16 onto the bus 18.

The controller 20 provides the state of the sensors 12 and cord sets 16 by a link 24 to a

monitoring/control system 26 (FIG. 4).

In the preferred embodiment, four sensors 12 are connected to each concentrator 14 and eight concentrators 14 are connected to the bus 18.

Referring to FIG. 2, the bus 18 is composed of conductors for power 28, clock 30 and data 32. The concentrators 14 are connected in parallel to the bus 18. The controller 20 provides power to operate the concentrators 14 and sensors 12 via the power conductors 28. The sensor connection system 10 is controlled by signals from the controller 20 on the clock conductors 28, which provide control and timing to each concentrator 14. The state of the sensors 12 and cord sets 16 is transmitted by the concentrators 14 to the controller 20 on the data conductors 32. Typically, the conductors 30, 32 will have characteristic impedance matching terminations on each end.

The power conductors may carry, for example, 30 volts d.c. The clock 30 and data 32 conductors may carry, for example, signals conforming to the RS485 standard. This standard uses a pair of conductors to carry a differentially encoded digital signal.

Referring to FIG. 3, an exemplary sensor 12 is composed of back-to-back zener diodes 34, 36 in series with a switch 38, all connected in parallel with a resistor 40. Other embodiments of the sensor 12 may be employed, as long as they exhibit the characteristics described below.

The condition-to-be-sensed 22 determines whether the switch 38 is "on" or "off."

The sensor 12 is connected to the concentrator 14 by a cord set 16. In the preferred embodiment, the cord sets 16 are commercially available pre-assembled cord sets having connectors at each end that mate with respective connectors on the concentrator 14 and sensors 12.

The concentrator 14 supplies a voltage V_c through a resistor 42 to the sensor 12. The voltage V_c may be, for example, 20 volts d.c. If the switch 38 is off, the voltage V_c is divided between the resistors 40, 42 which may be of such a ratio that, for example, the terminal 44 would be at 15 volts.

If the switch 38 is on, the voltage at the terminal 44 would be essentially determined by the zener voltage of the zener diodes 34, 36, for example, 10 volts. The diodes 34, 36 are connected in back-to-back configuration so that operation of the sensor 12 is not dependent on the polarity of the voltage applied to it.

The foregoing assumes that the cord set 16 is undamaged and functional. If the cord set 16 is open because, for example, it is not connected or has been broken, the voltage at the terminal 44 is at or near V_c . If on the other hand, the cord set 16 is shorted by, for example, crushing or other damage, the voltage at the terminal 44 is at or near 0

volts.

Thus, the voltage at the terminal 44 is indicative of the state of the sensor 12 (the switch 38 on or off) or the state of the cord set 16 (open or shorted). In order for state of the sensor 12 to be differentiated from that of the cord set 16, it must exhibit an impedance for its "on" state and for its "off" state that are not only different from each other, but also different from a shorted or open cord set.

The sensor 12 can be implemented in other ways, the important consideration being that it reliably provide an "off" impedance and an "on" impedance that are readily distinguishable from each other and from the impedances of a faulty cord set 16.

Existing switch-type sensors 38' can be employed with the sensor connection system 10 by eliminating the internal switch 38 of the sensor 12 and, instead, externally connecting the switch-type sensor 38' to a switch adapter 12' comprising the remaining portion of the sensor 12. This allows the retro-fitting of the connection system 10 to many existing sensors.

The logical state of the sensor 12 and cord set 16 are determined by a "short" comparator 46, an "open" comparator 48 and an "on/off" comparator 50.

If the voltage at the terminal 44 is below a threshold V_s (e.g., 8 volts), the short comparator 46 indicates a short in the cord set 16. If the voltage at the terminal 44 is above a threshold V_o (e.g., 17 volts), the open comparator 48 indicates an open in the cord set 16. If either a short or open is indicated, a logical error or fault signal is applied to a respective input to a shift register 52 (e.g., FAULT 1) by means of a "wired OR" and also to a fault indicator 49.

If the voltage at the terminal 44 is above a threshold V_d , the on/off comparator 50 indicates that the sensor 12 has sensed a first condition that has resulted in the switch 38 being off. If the voltage at the terminal 44 is below the threshold V_d , the on/off comparator 50 indicates that the sensor 12 has sensed a second condition that has resulted in the switch 38 being on. These conditions may be, for example, movement of a cam or lever, a pressure limit transducer, a proximity detector, etc. The on/off comparator 50 provides a logical signal representing the state of the sensor 12 to a respective input of the shift register 52 (e.g., DATA 1) and also to an indicator 51.

The indicators 49, 51 may be, for example, LEDs or other light sources.

It should be noted that the comparator 50 will provide an indication of the switch 38 being open or closed even if the cord set 16 is open or shorted, respectively. However, if a fault signal is

present, appropriate action can be taken to disregard the status of the sensor 12.

If for some reason only shorts or only opens in the cord set 16 are of interest, the open comparator 48 or the short comparator 36, respectively, can be eliminated.

Clock pulses from the controller 20 are provided on the clock conductors 30 (which are changed from RS485 signals to TTL signals by an unshown receiver). In the absence of a clock pulse for at least two pulse periods, the time out reset 54 resets the shift register 52 and the address counter 56.

The address counter 56 counts clock pulses after a reset. The counter 56 compares its count to a concentrator address 58. The counter 56 may be, for example, a 6-bit counter. The forth, fifth and sixth most significant bits can then be used to address up to eight different concentrators 14.

Once the count in the most significant bits of the counter 56 match the address 58, the shift register 52 reads the status of the sensors 12 and cord sets 16 and serially outputs that status on the data conductors 32 (the TTL signals are changed to RS485 signals by an unshown transmitter). At the same time the status is inverted by the inverter 60 and serially fed back into the shift register 52.

For example, if the address 58 of the concentrator 14 is "000", then for each of the first eight clock pulses (counter 56 counts from "000000" to "000111"), a data/fault bit is serially output from the shift register to the bus 18. Similarly, for a concentrator 14 with an address 58 of "010", eight data/fault bits would be output as the counter 56 counted pulses from "010000" to "010111."

For this example, the counter 56 wraps around after 64 clock pulses. Because the contents of the shift register 52 are inverted and fed back into the shift register 52, the whole process repeats for pulses 65 through 128, except that the logical status from each concentrator 14 is inverted.

Referring to FIG. 5, an exemplary graph of the logic data signal for the status of a concentrator 14 having an address 58 of "001" is shown. The graph indicates that a first sensor 12 is on and has no respective cord set 16 error, that a second sensor 16 is off and has no respective cord set 16 error and that the respective cord sets 16 of a third sensor 12 and a fourth sensor 12 are damaged (the status indicated for the sensors themselves thus being unreliable).

Referring to FIG. 6, the concentrator 14 producing FIG. 5 produces a logically inverted version of the signal of FIG. 5 in response to the second 64 clock pulses (for this concentrator, pulses 73 through 80).

In the manner described above, the status from individual concentrators 14 are time-division multiplexed onto the bus 18. For the first 64 clock pulses, the actual logical status is transmitted on the bus 18 and for the next 64 clock pulses the inverted logical status is transmitted. After 128 clock pulses, the process is repeated by the controller 20 delaying at least two clock pulse periods before again sending a stream of 128 pulses.

Referring to FIG. 4, a controller 20 includes a microprocessor 62 having on-chip RAM and program ROM. The microprocessor 62 supplies the clock pulses to the clock conductors 30 (the TTL signals are changed to RS485 signals by an unshown transmitter). The status data from the concentrators 14 are received by the microprocessor 62 from the data conductors 32 (the RS485 signals are changed to TTL signals by an unshown receiver).

A disable selector 64 is connected to the microprocessor 62 to instruct the microprocessor 62 to ignore the status of selected sensors 12. This allows the sensor connection system 10 to allow for sensors/concentrators that are not actually installed or to ignore chosen sensors. The selector 64 may be, for example, a series of individual switches.

A status display 66 displays the status of the sensor connection system 10 on, for example, LEDs. The particular status (e.g., sensor on/off status, cord set status, interconnect fault status, diagnostics, etc.) is selected by a status display selector 68 connected to the microprocessor 62.

In addition, whenever a cord set 16 error is detected, the microprocessor 62 provides an error indication on a cord set error indicator 70 (e.g., an LED).

The microprocessor 62 compares the status transmitted by the concentrators 14 in response to the first 64 pulses with that transmitted in response to the next 64 pulses (inverted status). If the status for each sensor 12 and cord set 16 for the first 64 bits and the second 64 bits do not exactly correspond to one another except for inversion, the microprocessor 62 indicates that a transmission error has occurred on a transmission error indicator 72 (e.g., an LED).

The microprocessor 62 also provides the status information to the monitoring/control system 26 by the link 24. Typically, the link 24 will be isolated and individually buffered parallel outputs corresponding to each of the sensors 12. Thus, to the monitoring/control system 26, it will be as if it is directly connected to each sensor. This allows the connection system 10 to be installed without the time, trouble or expense of changing the programming of an existing monitoring/control system 26.

For added capability, the controller 20 can provide the monitoring/control system 26 with cord set

and transmission error status. This can be used for alerting the machine operators and maintenance crews, who can also get the information from the status display 66. This greatly speeds correction of the problem, as once identified, a cord set 16 can be rapidly changed.

Another valuable advantage is that supplying the error status to the monitoring/control system 26 allows it to choose to ignore non-critical sensors or to shut down the system if critical sensors are lost.

Referring to FIGS. 7 and 8, a concentrator 12 is encapsulated to protect it from environmental hazards. Such materials as epoxy, rtv or polyurethane may be used as encapsulants.

Electrical connectors 74 mate with connectors on the ends of the cord sets 16. The bus 18 passes through the concentrator 14 via the connectors 76, 78, which mate with connectors on each segment of the bus 18.

It should be evident that this disclosure is by way of example and that various changes may be made by adding, modifying or eliminating details without departing from the fair scope of the teaching contained in this disclosure. The invention is therefore not limited to particular details of this disclosure except to the extent that the following claims are necessarily so limited.

Claims

1. A sensor connection system for connecting sensors to a process monitoring or control system, said connection system comprising:
 - a plurality of sensor units, each unit providing a first impedance in response to a first sensed condition or a second impedance in response to a second sensed condition, neither of said impedances being indicative of a short circuit or an open circuit;
 - a sensor cable connected to each sensor unit;
 - a concentrator connected to each sensor cable, said concentrator providing for each sensor unit a first logical signal in response to said first impedance, a second logical signal in response to said second impedance and a third logical signal in response to an error impedance, said error impedance being indicative of a short circuit or an open circuit in a respective sensor cable;
 - a bus connected to said concentrator for transmitting said logical signals; and
 - a controller connected to said bus, said controller causing said concentrator to provide said logical signals for each said sensor unit to said controller, said controller providing a status for each said sensor unit to said process monitoring or control system in response to

said logical signals.

2. A system according to claim 1, wherein said controller provides a clock signal on said bus and said logical signals are transmitted a first time on said bus by time-division multiplexing in response to said clock signal. 5

3. A system according to claim 2, wherein after said first transmission of said logical signals, said logical signals are transmitted a second time on said bus in inverted logical form in further response to said clock signal, said first and second transmissions being compared by said controller to detect transmission errors. 10

4. A system according to claim 3, further comprising a shift register in said concentrator, said shift register serially shifting said logical signals onto said bus for said first transmission, said logical signals also being logically inverted and serially fed back into said shift register and said shift register serially shifting said logically inverted signals onto said bus for said second transmission. 15

5. A system according to claim 1, wherein said bus provides power from said controller to said concentrators and sensor units. 20

6. A system according to claim 1, wherein said concentrator is encapsulated for protection from environmental hazards. 25

7. A system according to claim 1, further comprising a plurality of light sources on at least one of said concentrator and controller, said light sources providing visual indication of said logical signals. 30

8. A system according to claim 1, further comprising means for detecting an error in said transmitted signals. 35

9. A system according to claim 8, further comprising a light source on said controller, said light source providing visual indication of said detected error. 40

10. A system according to claim 1, wherein said controller includes means for providing said status for each said sensor unit to said monitoring or control system on a plurality of parallel status lines corresponding to each said sensor unit. 45

11. An adapter apparatus for connecting a sensor device to a sensor connection system, said 50

sensor device providing an open circuit to an applied signal in response to a first sensed condition or a short circuit to the applied signal in response to a second sensed condition, said apparatus comprising:
 a first impedance in series with said sensor device; and
 a second impedance in parallel with said sensor device and first impedance, said apparatus providing said second impedance in response to said first sensed condition or a third impedance in response to said second sensed condition, none of said impedances being a short circuit or an open circuit. 55

12. An apparatus according to claim 11, wherein said first impedance includes at least one zener diode and said second impedance is a resistance.

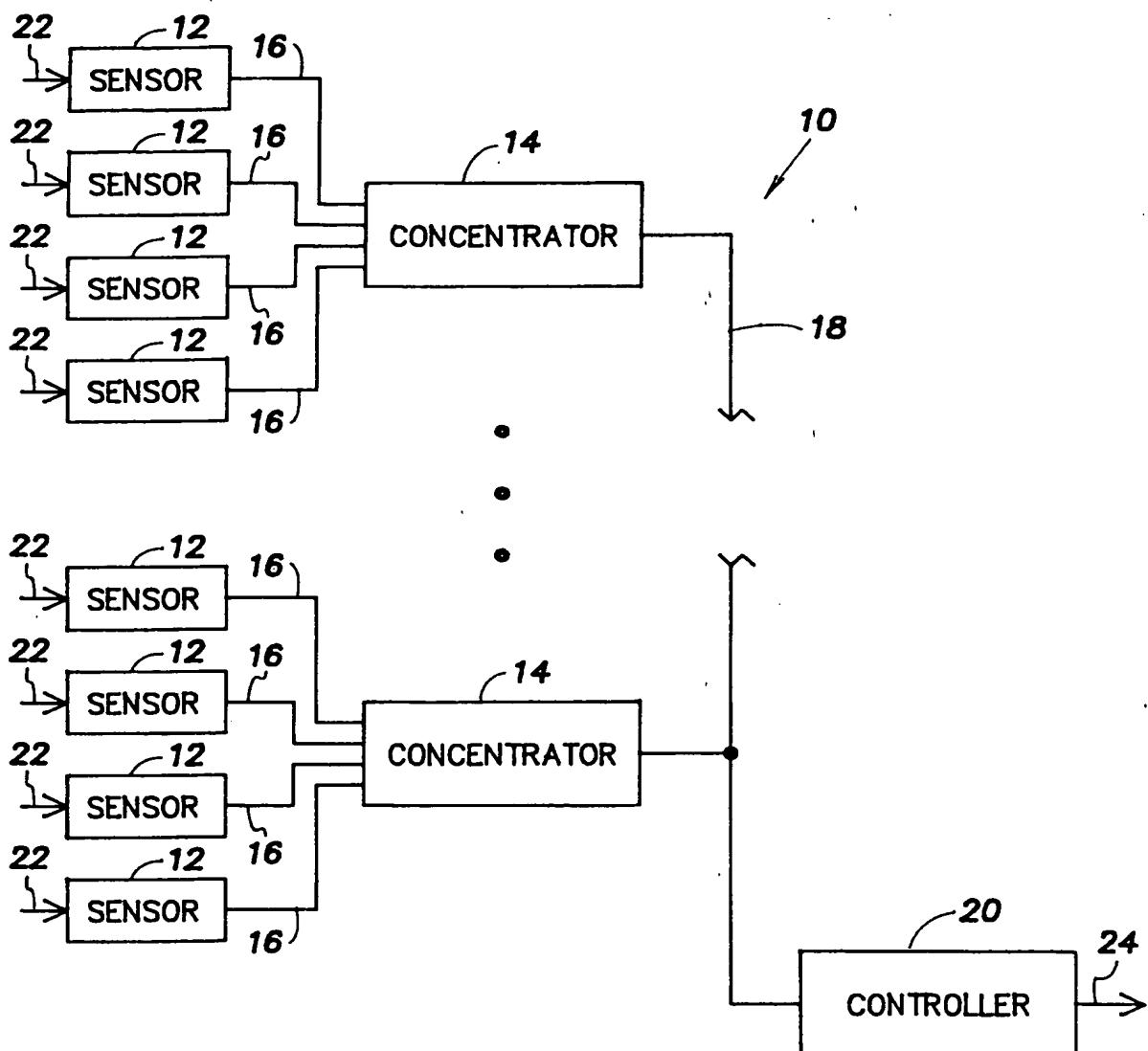


Fig. 1

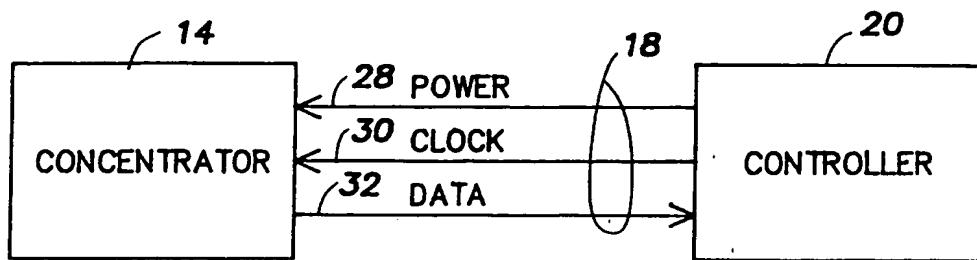


Fig. 2

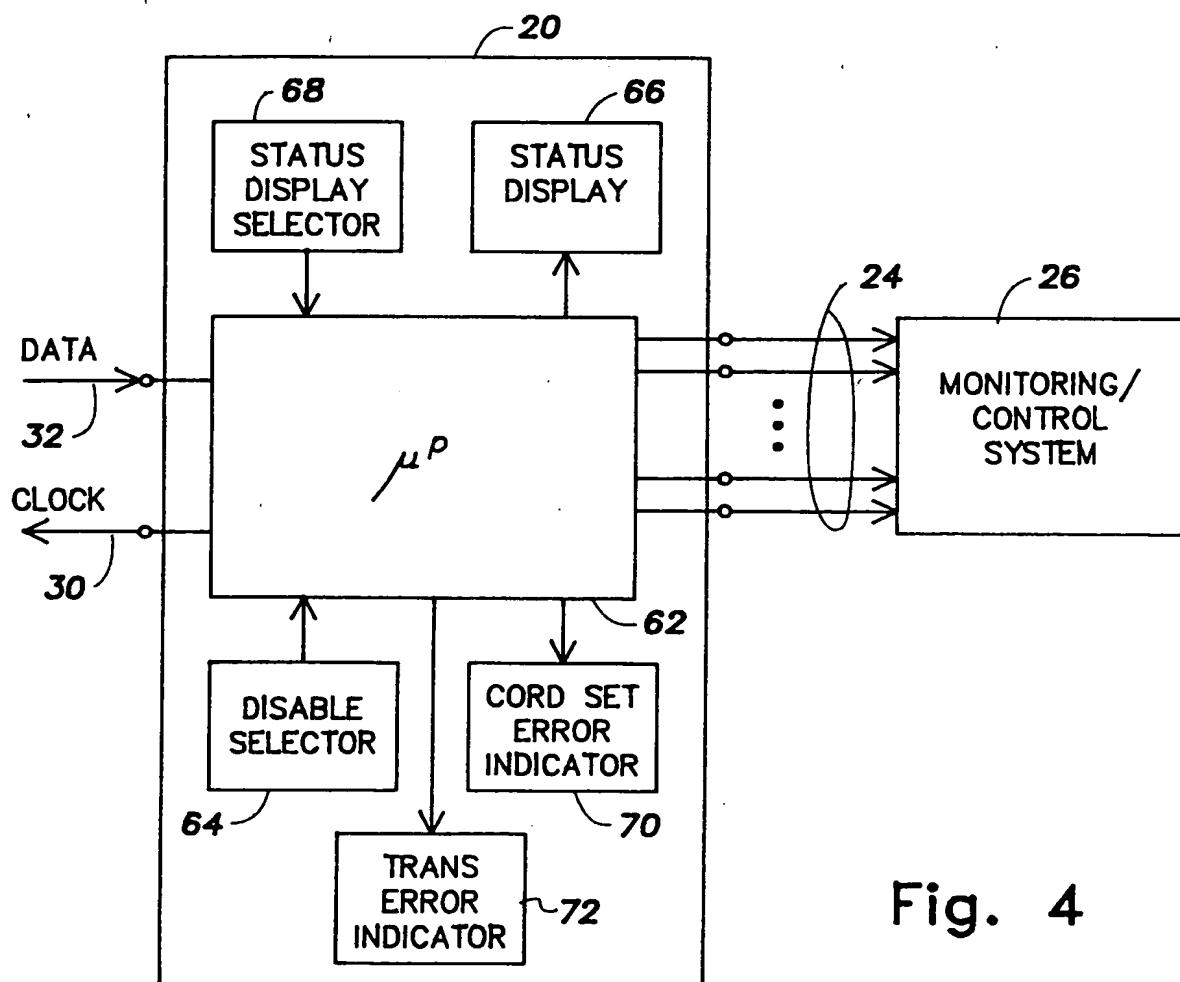
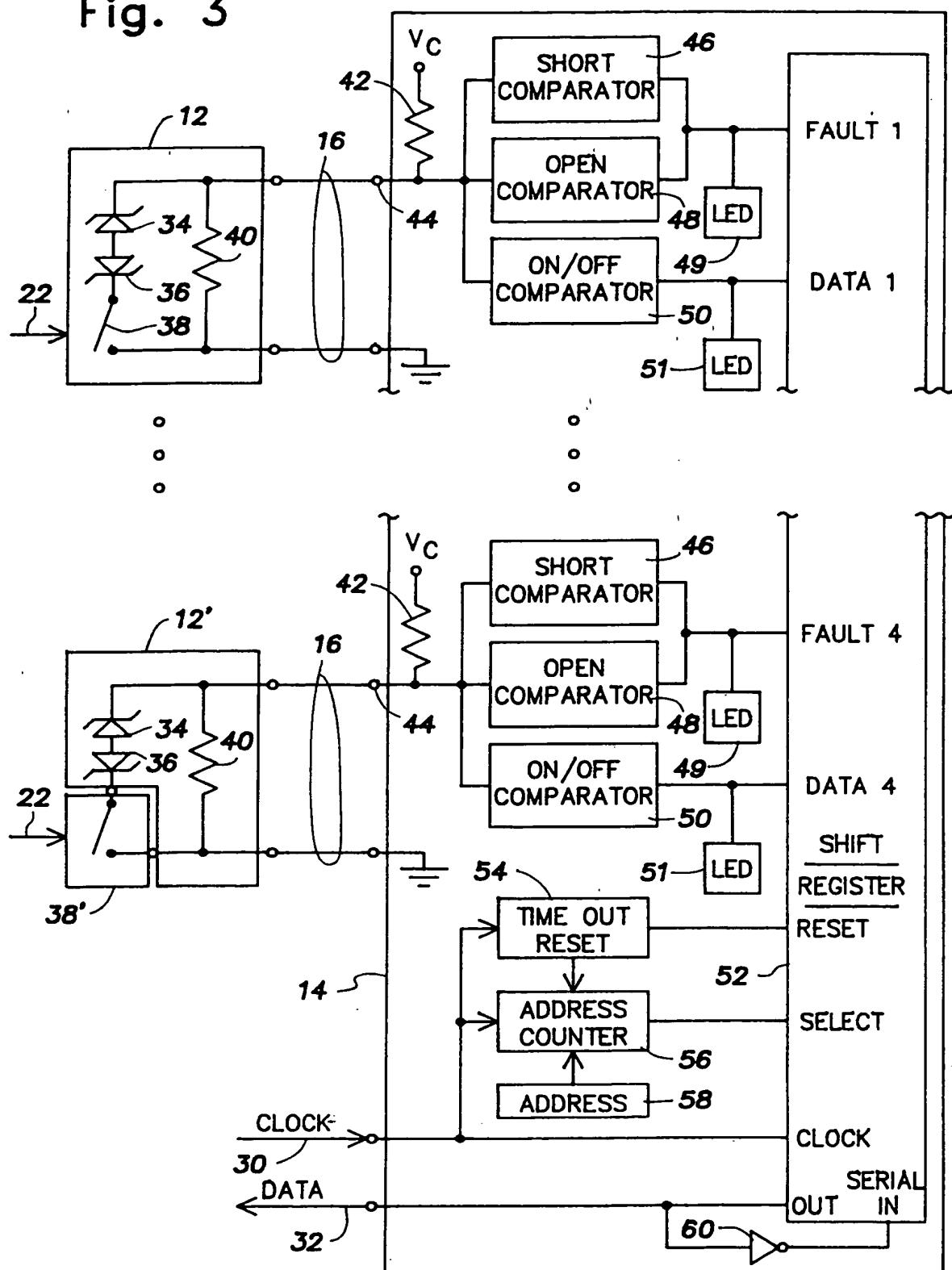


Fig. 4

Fig. 3



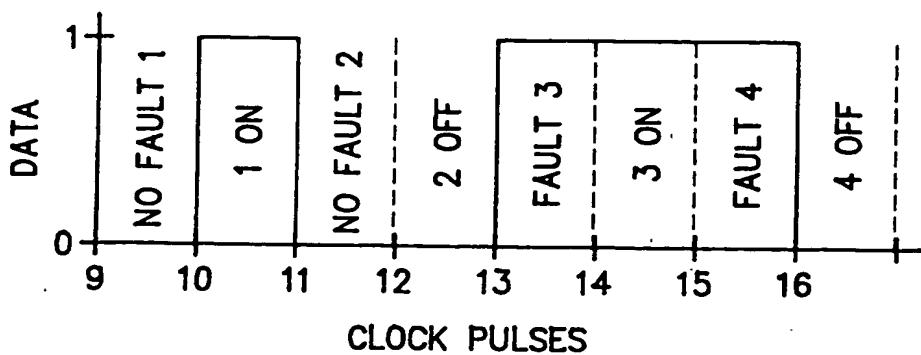


Fig. 5

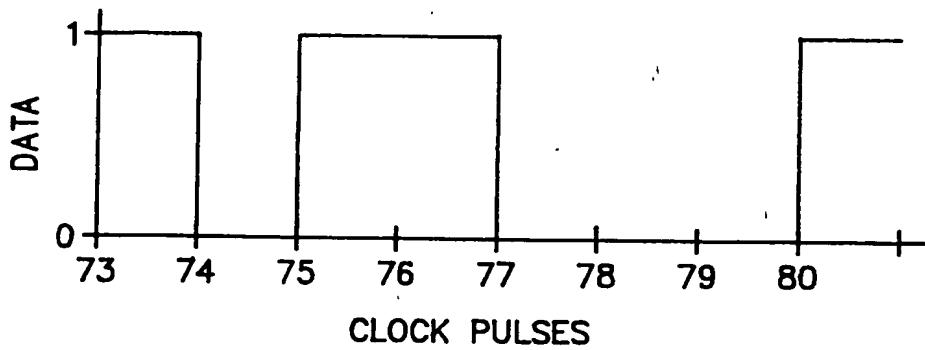


Fig. 6

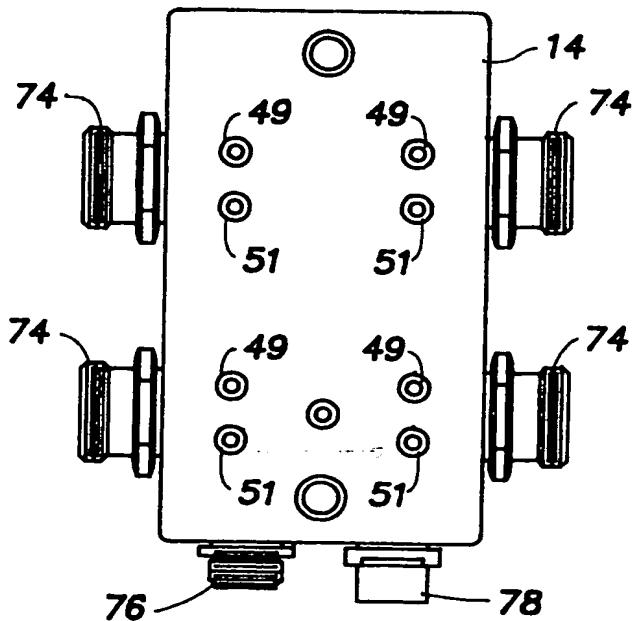


Fig. 7

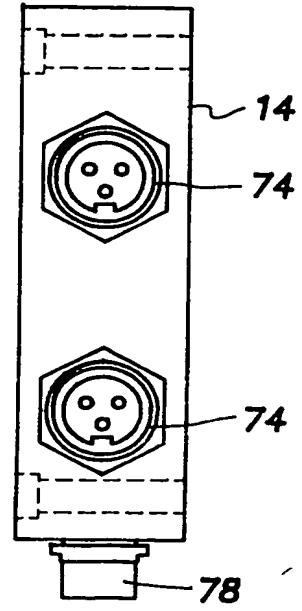


Fig. 8



European Patent
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EUROPEAN SEARCH REPORT

Application Number

EP 93 30 0899

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. CL.5)
Y	EP-A-0 068 482 (SIEMENS A.G.) * the whole document *	1	G05B19/04 G01R31/02
A	---	2,11	
Y	WO-A-8 909 147 (BOSCH G.M.B.H.) * the whole document *	1,11	
A	---	2-4	
Y	GB-A-2 115 577 (SQUARE D. COMPANY) * the whole document *	1,11	
A	---	2-10,12	
A	US-A-3 982 180 (BELL TELEPHONE LABORATORIES) * abstract * * column 1, line 32 - line 48 * * abstract; figure 3 *	1,7,9,12 1 7,9 12	

			TECHNICAL FIELDS SEARCHED (Int. CL.5)
			G05B G01R
<p>The present search report has been drawn up for all claims</p>			
Place of search	Date of completion of the search	Examiner	
THE HAGUE	14 MAY 1993	MOYLE J.F.	
CATEGORY OF CITED DOCUMENTS		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ----- & : member of the same patent family, corresponding document	
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